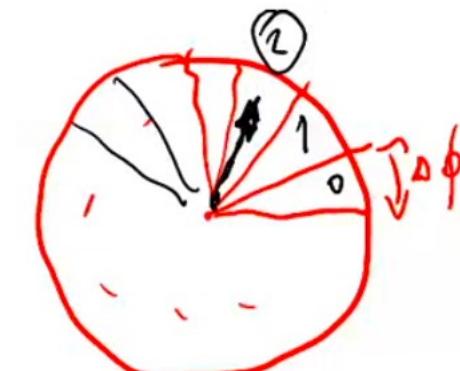
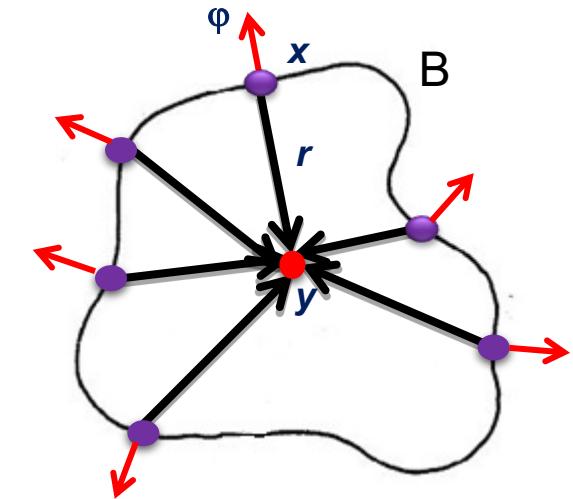


# Generalized Hough Transform

- The HT has been extended to detect arbitrary (i.e. non analytical) shapes:
  - Off-line Phase (build the object's model)
    - A reference point  $y$  is chosen (e.g. barycentre)
    - For each point  $x$  belonging to object's border  $B$ :
      - Compute gradient direction  $\phi(x)$ 
        - Gradient direction is quantized according to a chosen step  $\Delta\phi$
      - Compute vector  $r$  from  $y$  to  $x$  (i.e.  $r = y - x$  ).
4. An entry in the R-Table can contain several  $r$  vectors

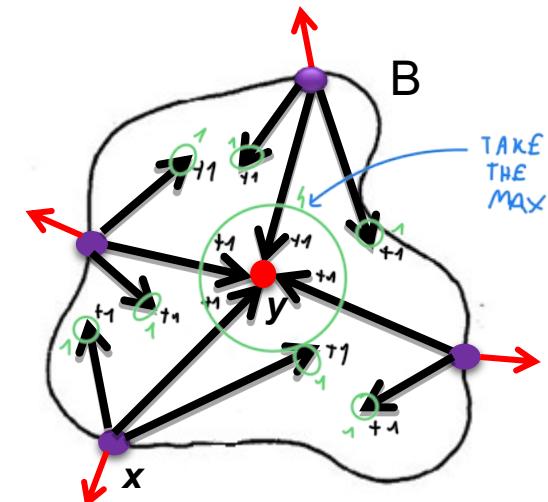
$i$	$\phi_i$	$R_{\phi_i}$
0	0	$\{r   y - r = x, x \in B, \phi(x) = 0\}$
1	$\Delta\phi$	$\{r   y - r = x, x \in B, \phi(x) = \Delta\phi\}$
2	$2\Delta\phi$	$\{r   y - r = x, x \in B, \phi(x) = 2\Delta\phi\}$
...	...	...



# Generalized Hough Transform

- On-line Phase
  1. We do edge detection first
  2. An image  $A[y]$  is initialized as accumulator array. For each edge pixel  $x$  of the input image:
    1. Compute gradient direction  $\phi$
    2. Quantize  $\phi$  to index the R-Table. For each  $r_i$  vector stored into the accessed row:
      1. Compute the position of the reference point  $y = x + r_i$
      2. Cast a vote into the accumulator array  $A[y]++$
  3. Instances of the sought object are detected by finding peaks of the accumulator array

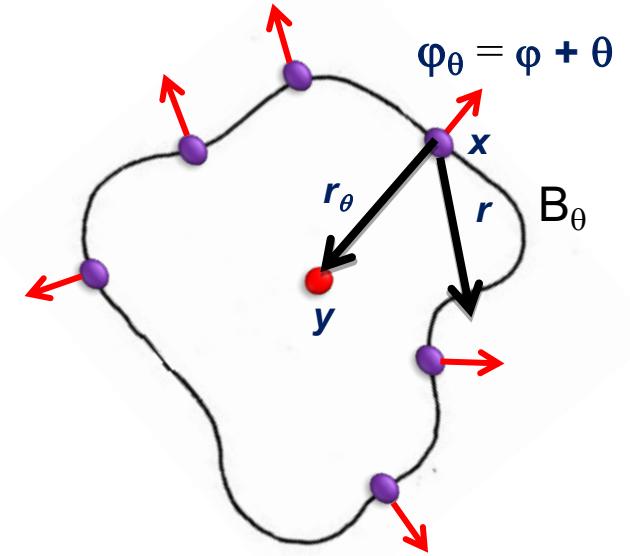
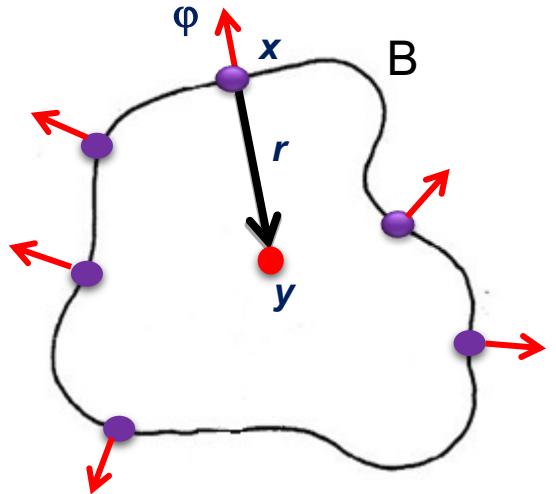
$i$	$\phi_i$	$R_{\phi_i}$
0	0	$\{r   y - r = x, x \in B, \phi(x) = 0\}$
1	$\Delta\phi$	$\boxed{\mathbf{r}_1, \mathbf{r}_2, \mathbf{r}_3}$
2	$2\Delta\phi$	$\{r   y - r = x, x \in B, \phi(x) = 2\Delta\phi\}$
...	...	...



Where is the baricenter?

# Generalized Hough Transform

- Can we find the shape if it is rotated?



- We do not know  $\theta$ , we should quantize rotation and try all of them!
- The same problem arises for scale

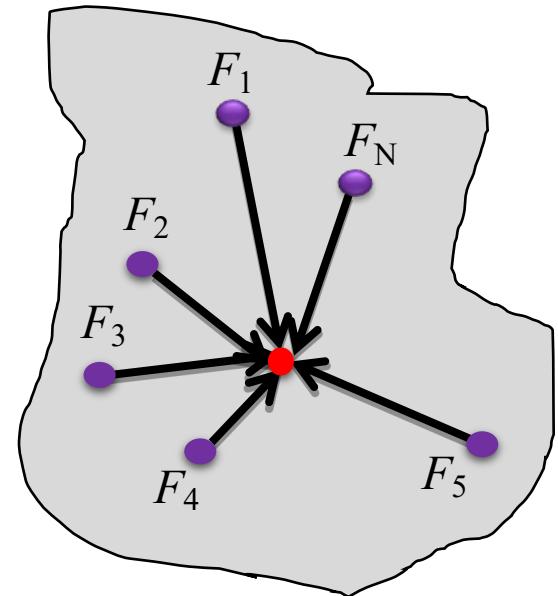
# Geometric Validation: Star Model

- Base the GHT feature on local invariant features (e.g., SIFT) and not on edge detection
- DoG features are not found along contour (edge are pruned...) they are found within the object
- Off-line phase:
  - Detect features for each feature points
    - (position, canonical orientation, scale, descriptor)
  - Compute the baricenter and build a star model

$$F = \{F_1, F_2 \dots F_N\}, F_i = (\mathbf{P}_i, \varphi_i, S_i, \mathbf{D}_i)$$

$$\mathbf{P}_C = \frac{1}{N} \sum_{i=1}^N \mathbf{P}_i \rightarrow \mathbf{V}_i = \mathbf{P}_C - \mathbf{P}_i$$

- Add  $\mathbf{V}_i \Rightarrow$  the joining vector  $\forall F_i \in F$   $F_i = (\mathbf{P}_i, \varphi_i, S_i, \mathbf{D}_i, \mathbf{V}_i)$
- No longer use the R table



# Geometric Validation

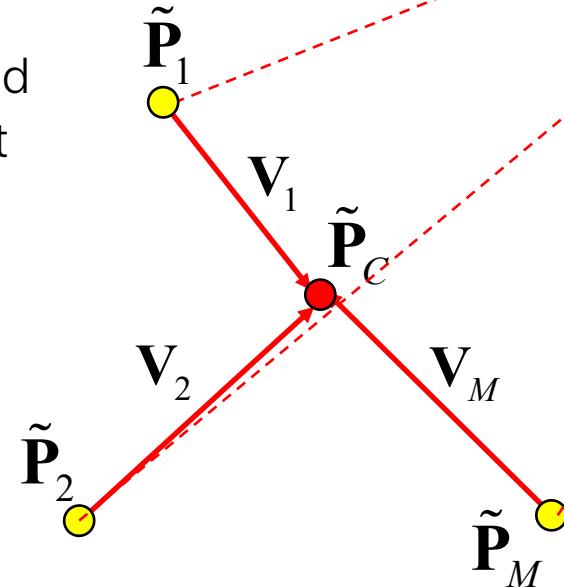
On-line phase

- Extract features from target image
- Match features from the target image to the template
  - Now the matching is based on descriptor not gradient directions

$$\tilde{F} = \{\tilde{F}_1, \tilde{F}_2 \dots \tilde{F}_M\},$$

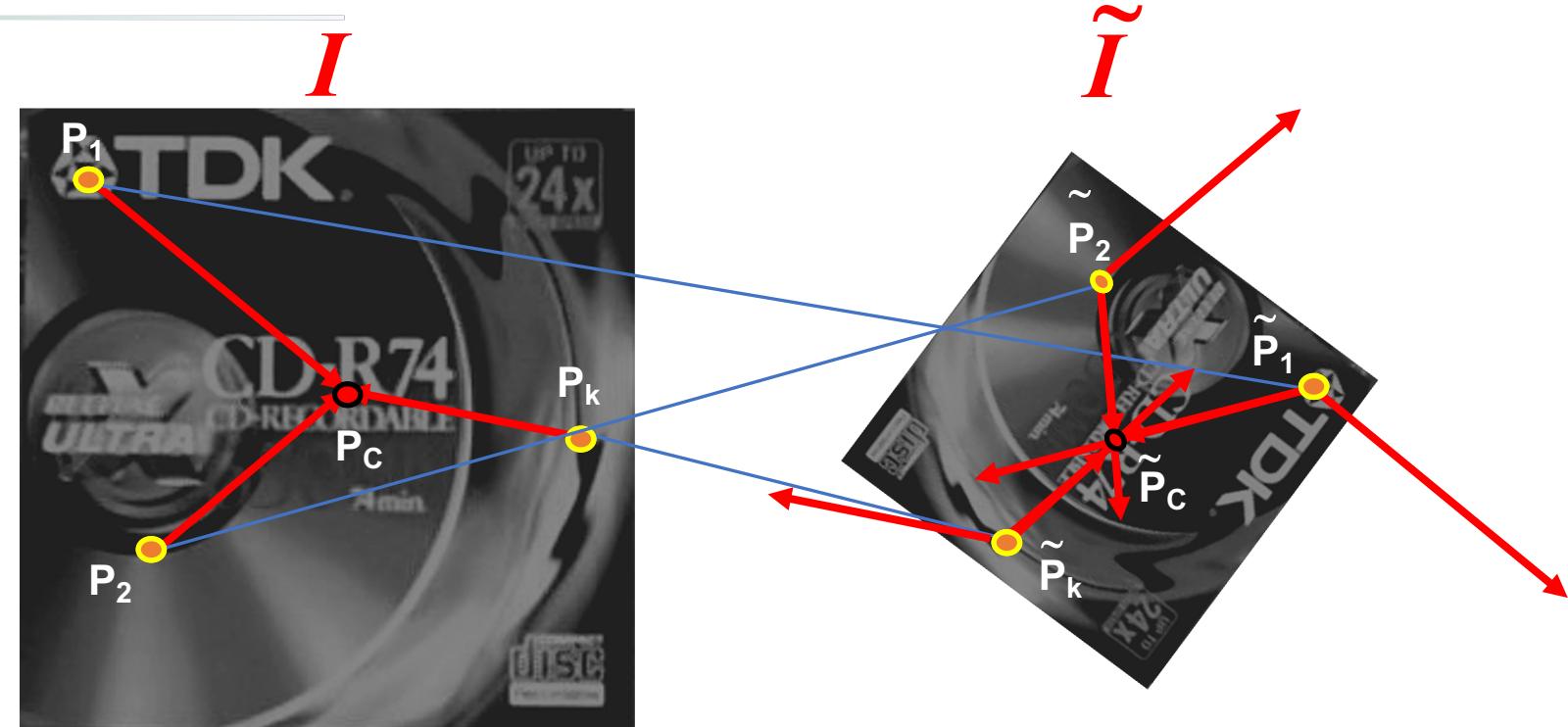
$$\tilde{F}_i = (\tilde{\mathbf{P}}_i, \tilde{\varphi}_i, \tilde{S}_i, \tilde{\mathbf{D}}_i)$$

$$\tilde{D}_i \Leftrightarrow D_i, i = 1 \dots M$$



# Similarity Invariant Voting

- The joining vectors are not pointing coherently towards the reference point
- We should:
  - rotate all of them by the rotation obtained as the difference with the canonical rotation
  - Scale them according to the ratio of scales



$$F_i = (\mathbf{P}_i, \varphi_i, S_i, \mathbf{D}_i, \mathbf{V}_i)$$

$$\tilde{F}_i = (\tilde{\mathbf{P}}_i, \tilde{\varphi}_i, \tilde{S}_i, \tilde{\mathbf{D}}_i)$$

$$\Delta\varphi_i = \tilde{\varphi}_i - \varphi_i$$

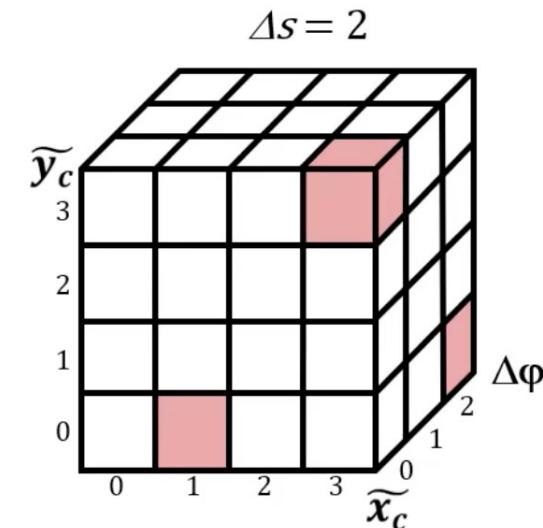
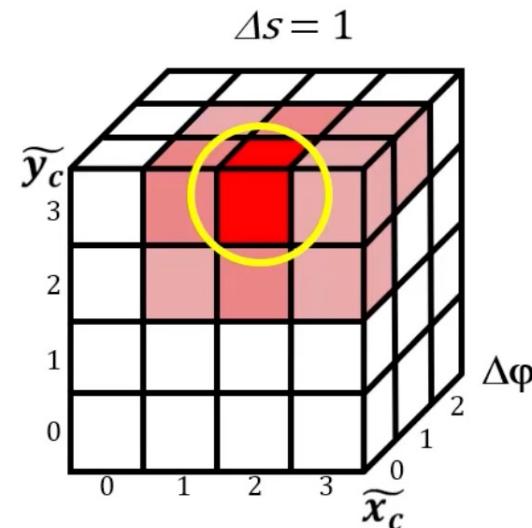
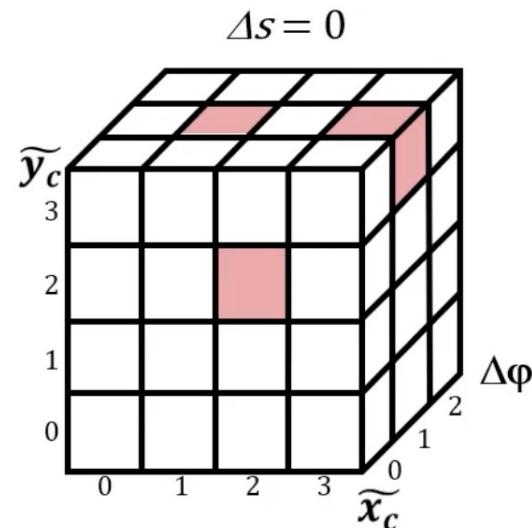
$$s_i = \frac{\tilde{S}_i}{S_i}$$

$$\tilde{\mathbf{P}}_{C_i} = \tilde{\mathbf{P}}_i + s_i \cdot \mathbf{R}(\Delta\varphi_i) \mathbf{V}_i$$

$$\mathbf{A}[\tilde{\mathbf{P}}_{C_i}] + +$$

# Voting process

- Each match cast a vote for the position of the baricentre
- Use an accumulator array (quantized), increment each translation bin if a prediction hits a specific quantized position (voting process as before).
- The accumulation array is 4 dimensional because we need to accumulate also on the base of the rotation and scale hypothesis, otherwise we accumulate in the same translation bin but for different hypothesis of rotations and scales.



# Example

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